



Natural Resources
Canada



Energy
Technology
Futures

The Future of the Canadian Electricity Sector

Draft #1

Energy Technology Futures Workshop
March 9th and 10th, 1999
Royal York Hotel
Toronto, Ontario

Canada



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The Energy Technology Futures (ETF) project of Natural Resources Canada sponsored the above workshop with the objective of examining the long-term (to the year 2050) technological opportunities for the production, transmission and distribution of electricity within Canada on a sustainable basis, i.e. with reduced greenhouse gas (GHG) emissions. Workshop attendees are listed in Annex 1.

This workshop is part of the ETF initiative to identify technologies that could come into play in the period 2030 to 2050 and which could fundamentally alter the relationship between the growth of GHG emissions in Canada and the growth of the economy. The specific objectives of the workshop were to:

- brainstorm on potential visions of the nature and structure of the Canadian electricity sector in 2030-2050
- identify key technologies for the generation, transmission, distribution and storage of electricity
- identify R&D technology issues, gaps, and critical technologies.

These objectives were examined by means of workshop break-out groups from three points of view: (i) Canadian regional opportunities, (ii) technologies that could emerge (step-out) over the long term, including centralized versus decentralized power systems, and (iii) enabling or cross-cutting technologies required to allow implementation of the 2030-2050 electricity sector vision. Summaries of discussions at these break-out groups are presented at the end of the report.

Key Conclusions and Observations

The goal of the workshop was to arrive at the "best bet" for what GHG-limiting technologies would be used in Canada's electricity sector in the year 2050. Presentations to the workshop in plenary session offered no "silver bullets" but concluded that electricity would continue to be generated from all sources at a variety of scales, both centralized and distributed, with an emphasis on low carbon intensity in the case of fossil fuels. Hydrogen as an energy carrier would eventually share the electricity system.

The overall vision for the electricity system in 2050 was characterized as:

- continuing from the present with greater electrification, improvements to existing systems, and with greater exports

- **diversified** in terms of energy sources, infrastructure and technologies, and being more **distributed** than at present, although some "central" utility companies would still exist
- **integrated** in terms of regional and technological systems with generation at all scales, from "plexes" to appliances
- **clean** with close to zero carbon emissions
- **intelligent** with artificial intelligence (AI) being the norm for infrastructure systems, demand and supply management; uncertainty would be managed effectively.

Technologies to attain this vision of the fully-integrated electricity system in 2050 were summarized under the following headings:

- Generation
- Transmission
- Storage
- Enabling Technologies
- Energy Management Systems and
- Canadian Opportunities and Niches.

In order to arrive at this vision for 2050, the workshop concluded that basic research and the encouragement of innovation should be primarily focused in the area of generation. Investments in the other areas would follow in the order: storage > energy management systems > enabling technologies > transmission.

"High megawatt" (in the 1000's) generation technologies deemed to show the most promise were: combined-cycle coal gasification, coal/oil sand/nuclear/fuel cells energy plexes with CO₂ capture, high-efficiency gas turbines, large hydro, wind farms, and new and advanced nuclear. "Low megawatt" (10's to 100's) promising technologies were biomass complexes, community solar projects, mini hydro, hybrid fuel cell/gas turbines, and run-of-river power generation.

The workshop identified several Canadian opportunities and niches for generation. Those pertaining to the technologies of most promise were: retrofittable O₂/CO₂ combustion techniques for coal-fired plants and clean (carbon-neutral) fossil technologies in general, advanced nuclear, biofuels, fuel cells, mini and micro hydro, and wind/hydro optimization.

Barriers to future implementation of these technologies included cost, uncertain infrastructure characteristics for centralized and distributed power, the reliability of new technology, intermittency of energy supply (for wind and solar), storage, fear of wasting valuable resources (for fossil fuels), and biomass support technologies.

Technologies in the other areas (in order of importance) considered to show the most promise were as follows:

Storage:	regenerative (reversible) fuel cells, hydrogen as a storage material, advanced batteries
Energy Management Systems:	community energy planning, waste as the second resource, low-cost hydrogen, and co-biogenesis
Enabling Technologies:	sequestration and capture technologies, advanced heat pumps
Transmission:	flexible AC transmission (FACT); long-distance power wheels to take advantage of low-cost energy sources such as flared gas from the North Slope, advanced power systems and controls (e.g. switching and quality), and superconductivity.

Of particular note is that workshop participants felt strongly that unknown surprise or disruptive technologies would probably play a determining role in the characterization of the electricity sector of the future, that is to say the probability of predicting the future with any degree of accuracy is low.

Workshop Summary

Following a presentation to the workshop by Kevin Cliffe, Director, ETF Project (Annex 2), on the methodology for the Energy Technology Futures Project, views on the future of the electricity sector were presented to the workshop by

- Steve Gehl, Director, Strategic Technology and Alliances, the Electric Power Research Institute (EPRI), Palo Alto, California, (Annex 3)
- Mark Tinkler of Ontario Hydro Technologies, (Annexes 4 and 5)
- Christine Elwell of the Sierra Club of Canada (Green Energy Coalition Fact Sheet as Annex 6).

Workshop participants then participated in a round-table "future scan" to brainstorm key technologies which could become a part of Canada's electrical system and which provide opportunities that do not presently exist for lower GHG emissions. Ideas from this session are listed in Annex 7.

Following reports in plenary from the three break-out groups (geographic, technology step-out, and vision/enabling technologies), lists were distilled of 2050 electricity sector technologies under the headings of generation (both high and low megawatt contributions), transmission, storage, enabling technologies, and energy management systems. Workshop participants used an investment dollar-related voting procedure to select those technologies which they considered to

hold the most promise. Participants then identified barriers to the introduction of these technologies into the Canadian electricity sector. Finally, they identified Canadian niches and opportunities for future technology innovation and development.

Summary of Presentations to the Workshop

1. Electricity Technology Roadmap, Steve Gehl, EPRI

The EPRI Electricity Technology Roadmap Initiative, which is an ongoing activity, has developed a comprehensive vision of opportunities for electricity-related innovation to benefit society and business. This vision has been translated into a set of technology development destinations and R&D pathways. The motivation for embarking on this initiative was provided by the restructuring of the electricity industry, pressures to reduce costs associated with the industry, and the need to plan for the long-term. The Roadmap calls for customer-managed services and resolution of delivery system vulnerability by 2003, acceleration of U.S. competitiveness and leadership by 2010, resolution of the energy/carbon conflict by 2015, and ability to manage the global sustainability challenge by 2025.

With respect to delivery systems, even though many distributed generation sources are attractive, their costs per kilowatt are usually higher than from central generation. In fact, improved transmission systems and distributed generation are in competition, but both need R&D dollars.

Man's impact on the environment, "the global footprint", will be a thousand times greater in 2050 than it was in the 1950's, about 90% of this being attributable to developing countries. Opportunities must be sought to reduce this global footprint. Carbon intensity of world primary energy will decrease from 1 to about 0.55 tonnesC/tonne oil equivalent. The world will require an extra 10,000 GW (100 million MW) of global generating capacity, which means a tripling of current world power plant capacity, adding 200,000 MW/year, and investing \$100-150 billion(US)/year. To put these requirements into perspective, this additional global generating capacity is equivalent to less than 5 years of current automobile engine production and the costs will be less than world spending on cigarettes.

It will require a broad portfolio of options with no "silver bullets" saving the day and encompassing fossil, nuclear, renewables and central and distributed/dispersed options. However, successful development and deployment of the following technologies could be turning points and limit-breaking: coal refining, carbon sequestration, advanced nuclear power, distributed renewable power systems, solar-powered satellites, and an electricity/hydrogen infrastructure.

Because global population will quadruple between 1950 and 2050 and urbanization will grow even faster, global sustainability will require a >2% per annum growth in emission reduction. This scenario requires electricity to supplant oil for electricity production plus an innovative

portfolio of generation options. Decarbonization leading to an electricity/hydrogen system is achievable.

Steve Gehl concluded in a quote from Nathan Myhrvold of Microsoft which underlined the absolute necessity of society to spend more on science in order to continue to enjoy a technologically-based economy vital to the realization of the full potential of the next millennium.

Note: Copies of the overheads used by Mr. Gehl are in Annex 3.

2. Emerging Trends in Electric Power Generation, Mark Tinkler, Ontario Hydro Technologies

Within the geological time frame, the world oil and gas supply curves will reach their maximums before the middle of the next century. Coal supply remains dominant and lasting. Renewables and nuclear energy are very long range and have barely started to grow. The forces of change have encouraged technology roadmapping. Examples of these forces of change include growth in fossil power generation, advantages of economy of scale to reduce generation costs, the move toward smaller scale, and increased conversion efficiency such as from the use of gas turbines.

In speculating future electricity sector fuel sources, natural gas use in the developing world was predicted to increase. Because coal use will remain dominant, CO₂ emissions from coal will increase by more than 50%. Thus, fossil fuels will inevitably dominate energy supply and world CO₂ emissions from power generation will continue to grow. The contribution from nuclear was foreseen to remain flat and the portion from renewables to remain relatively small, although small hydro was predicted to grow.

Distributed generation, which is small-scale, close to load, and is flexible and modular, is an emerging option to reduce emissions. It is already cost-competitive, especially in the cogeneration mode, because transmission and distribution losses are minimized. Energy service companies (ESCO's) will benefit from distributed generation. Technologies for small-scale generation include small gas turbines and pressurized high-temperature solid-oxide fuel cells, with gas-turbine/fuel cell hybrids. These technologies have the potential to reduce CO₂ emissions by up to two thirds. However, this will still not be enough, necessitating higher efficiency central generation with coal gasification coupled with CO₂ capture and sequestration.

An electricity sector roadmap from the Oak Ridge National Laboratory was presented (Annex 5), showing a time-line of anticipated technologies at five-year intervals to 2030. However, in predicting the future, the appearance of unforeseen "disruptive" technologies which can radically change today's structure, but which are dismissed because they are not yet commercial, is an ever-present possibility.

Note: Copies of the overheads used by Mr. Tinkler are in Annex 4. A summary of CO₂ reduction technologies from Oak Ridge Laboratories is found in Annex 5.

3. Energy Futures, Christine Elwell, the Sierra Club of Canada

Ms. Elwell agreed with the previous speakers that the energy supply future would encompass a full palate of technology options but underlined that the potential for renewables to displace traditional fuels is virtually unlimited. She noted that we can assume that unit costs for renewables and other high-technology options will come down. The global market for wind now exceeds \$1.5 billion(US) and is expected to reach \$3 billion by 2002, which is impressive for an industry that started virtually from scratch in 1992. The cost of solar power has dropped from 13 to 10 cents/kWh (Cdn).

Despite these positive trends, Ms. Elwell underlined that it remains important to provide the incentives necessary to overcome current market and trade barriers to renewables. Deregulation may provide the opportunity to eliminate inappropriate government subsidies in the form of support programs, as well as the internalization of environmental costs. In the United States, it has been suggested that there be 10% renewables in the energy supply portfolio (the "renewable portfolio standard") which would cost only about \$1.30 (US) on household electricity bills. Ms. Elwell suggested that a 10% renewable energy portfolio also be a requirement for Canada, and that the use of "Green Power" should be encouraged by the forgiveness of transmission and debt costs.

As well as considering policy issues for the encouragement of the introduction of renewables and underlining their environmental benefits, the Sierra Club of Canada is also emphasizing the long-term security of supply issue.

Note: A fact sheet provided by Ms. Elwell is found in Annex 6.

Synthesis of Electricity Technologies to the Year 2050

Following presentation of the results from the three break-out groups (geographic, technology step-out, and vision/enabling technologies), technologies for the year 2050 were listed and participants were given the opportunity to provide their views on the relative importance or potential contribution that each of the technologies could play.

Participants also voted on which of the key technology areas investments would be the most advantageous for a less carbon intensive 2050 electricity economy. The results of this voting, in relative order of importance, were as follows:

- Generation
- Storage
- Energy Management Systems

- Enabling Technologies, and
- Transmission.

The lists below for technologies within each key area are also in relative order of importance.

1. Generation

(a) "High" Megawatts:

- combined-cycle coal gasification
- coal/oil sand/nuclear/fuel cells energy plexes with CO₂ capture
- high-efficiency gas turbines
- large hydro
- wind farms
- new nuclear
- advanced fission, more integrated fuel cycles
- O₂/CO₂ based coal-fired power stations producing CO₂ for sale
- nuclear/H₂ enerplex also with large-scale PV and H₂ production
- closed-cycle coal
- clean fossil technology
- "space tether", generating electricity by cutting earth's magnetic field in synchronous orbit

(b) "Low" Megawatts:

- biomass complexes
- community solar projects
- mini hydro
- hybrid fuel cell/gas turbine
- run-of-river
- vertical axis wind turbine
- tidal and wave power
- personal (home) power plants using fuel cells and hydrogen
- localized small devices, nanotechnologies
- trigeneration and local energy integration
- biomass energy
- free stream turbines
- waste energy
- high-efficiency wide-spectrum photovoltaics
- geothermal
- optimally isolated renewable central power generation, wind and PV with low losses
- thermoelectric power production
- micro Sterling engines
- smart generating materials, e.g. PV paints
- added generation by ground-water heat pumps

- integration of solid-oxide fuel cells into closed systems
- ram-jet turbines
- wind/wave combination

2. Transmission

- flexible AC transmission (FACTS); long-distance power wheels to take advantage of low cost energy sources such as flared gas from the North Slope
- advanced power systems and controls (e.g. switching and quality)
- superconductivity - thin film (1 micron) yttrium/barium copper oxide conductors with current carrying capacity in magnetic fields operating in liquid nitrogen (77°K)
- mini grids
- LVDC,
- eco-industrial parks, direct current
- wireless power transfer with lasers and microwaves
- HVDC, low-loss efficient switching
- new gas pipeline infrastructure to support energy integration
- space-based solar transmission

3. Storage

- regenerative (reversible) fuel cells
- hydrogen as a storage material
- advanced batteries
- CAES, compressed air energy storage
- optimization of reservoirs using renewables, e.g. wind
- SMES, superconducting magnetic energy storage
- advanced flywheels

4. Enabling Technologies

- sequestration technologies
- capture technologies
- advanced heat pumps
- computer-based controls, AI
- nuclear waste management
- advanced and exotic materials at lower cost
- integration of power provided simultaneously by different fuels
- more efficient pumps, e.g. for CAES
- high-pressure H₂ embrittlement
- lightweight systems for gas (H₂) storage
- MHD, magnetohydrodynamics
- advanced manufacturing technologies
- synthetic fuels manufacture
- nanotubes for H₂

5. Energy Management Systems

- community energy planning
- waste as the second resource; linking it to feedstocks
- low-cost hydrogen
- co-biogenesis, use of energy (possibly waste) to enhance carbon cycle sequestration through coproduction of fertilizers, irrigation water, etc.
- smart living, computerized control systems for communications and electricity, automated demand management
- fully-integrated industrial ecosystems
- sequential processing with no waste
- large city cogeneration/district heating infrastructures
- super energy efficiency (lighting, heating)
- self-sufficient rural community homes

One other item was included in the voting process, "Unknown surprise or disruptive technologies"; this item received a significant number of votes.

Barriers to Technology Implementation

While the above synthesis was being developed, workshop participants were asked to identify barriers or roadblocks to their ultimate implementation. These are grouped below under the headings: technology barriers; societal resistance and "people" issues; investments/money; role of government; business/full cost accounting; and institutional. Note that some of these barriers could fall under more than one category.

Technology Barriers

- wind: intermittency, storage
- solar: diffuse and hard to collect, intermittency, materials, storage, capacity factor
- wood waste power generation: reliability, ceramic heat exchangers, hot-gas clean-up, small high-efficiency turbines
- biomass complexes and biorefining: identification of extractives which vary between species, e.g. pharmaceuticals, fire retardants and food, methods of extraction
- biomass in general: slower tree growth rates in colder climates, more efficient grinding to hog fuel required, transportation, biomass fuel handling systems, integration into tree-farm licences
- regenerative fuel cells: membrane materials
- superconducting power systems: materials, high-temperature superconductors
- fossil plant lifetime may be a barrier to effective CO₂ capture and sequestration

Societal Resistance, "People Issues"

- nuclear fission: reliability and management of spent fuel, public education
- fossil fuels: inappropriate use of a valuable resource
- more open-mindedness required
- "NIMBY" syndrome

Investments/Money

- solar: high cost per kW, no Canadian manufacturing capability
- wood waste power generation: cost
- biomass in general: tree harvesting costs
- regenerative fuel cells: economies of production
- economy of scale is a barrier to small-scale generation, for example micro turbines and fuel cells may be too expensive
- lack of demonstration projects
- nuclear fission: development risks over long project life (>40 years)

Role of Government

- large hydro: transmission of electricity to markets and inadequate risk and environmental assessment, fish diversion upstream and downstream
- regulatory uncertainty, patchy nature of deregulation
- incentive to go beyond Kyoto targets?
- self-sufficient rural communities/homes: political will
- recognition of need for a centrally-integrated system

Business/Full Cost Accounting

- energy-loss full cost accounting required
- environment costs not captured
- emergence of carbon as a commodity
- self-sufficient rural communities/homes: capital markets

Institutional

- renewables: integrated central/distributed systems
- DSM: belief that conserving energy is not a business, lack of training in utilities and in ESCO's (energy service companies)
- hydrogen: infrastructure, adaptation by auto industry

Canadian Opportunities and Niches

Finally, in development of characteristics of the fully-integrated energy system for the year 2050, particular Canadian niches and opportunities for technology innovation and development were identified. These are grouped below:

1. Generation

- retrofittable O₂/CO₂ combustion techniques for coal-fired plants and clean fossil technologies in general
- carbon-neutral fuel systems, biofuels and hydrogen
- power for the North (international opportunity?)
- wind/hydro optimization
- fuels cells: natural gas reforming and hydrogen electrolysis
- improved nuclear fission: development of new systems to extract maximum energy from uranium and thorium fuel sources, international implications of an improved nuclear supply system based on CANDU
- large hydro
- mini and micro hydro

2. Transmission

- emission-free transportation by electrification
- long transmission lines minimizing transmission and distribution losses (Canada is a large country)
- transmission management, software control
- district heating

3. Storage

- reservoirs
- hydrogen and fuel cells

4. Enabling Technologies

- CO₂ management technologies, capture and sequestration
- EOR (enhance oil recovery) using CO₂ injection
- support technologies for non-Canadian fuel cells, e.g. pressure vessels, power conditioning, heat exchangers
- DSM: e.g. replication of Energuide Program to all sectors
- high-temperature superconductors for power systems, improve flexibility, reliability and cost/performance

5. Energy Management Systems

- technologies for the hydrogen economy

Breakout Group "A" **Geographic – The "Explorers"**

Team Members

Tom Beese, National Electricity Roundtable
Daphne Cheel, Alberta Science and Research Authority
Jessie Davies, University of New Brunswick
Terry MacDonald, Nova Scotia Power
Terry McCullough, BC Hydro
Mike Saxton, Manitoba Hydro
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Mark Egner, GCSI (facilitator)
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Challenge

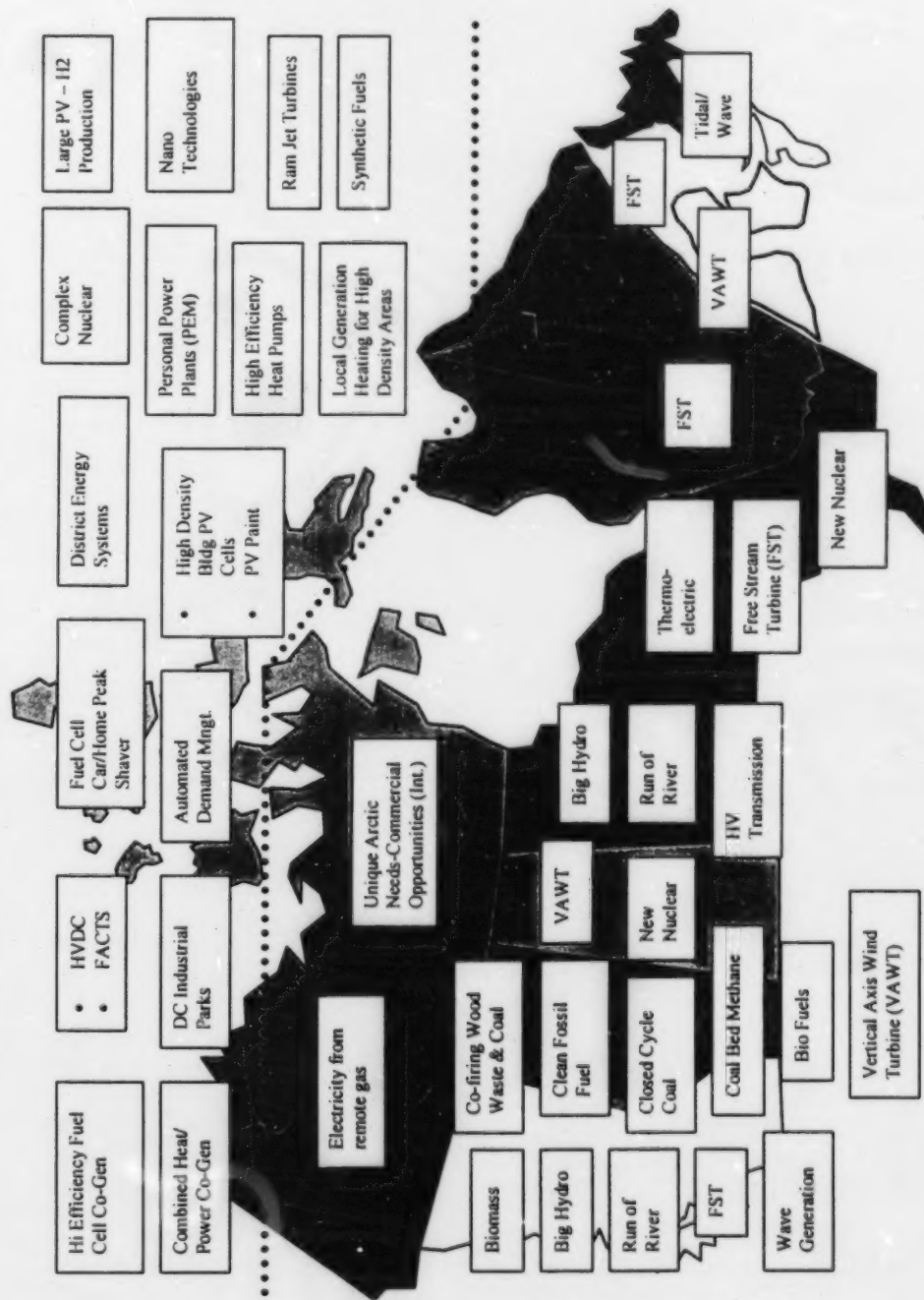
The challenge for the group was to explore potential future technologies that could produce, transmit and distribute electricity, in the years 2030 to 2050, and to consider the geographic nature of these technologies both from a regional and urban/rural basis. The group decided to focus on those technologies that would not only help reduce GHG emissions, but also those with broader environmental benefits and particularly those that could be sustainable on a full life cycle basis. The group also considered substitutes for electricity generation (e.g., demand side management) and enabling technologies within this context. While the geographic nature of the challenge was centered on Canada, it was recognized that a broader global context is likely required.

In order to facilitate the brainstorming, the group decided to assume that, in the future, the policy framework would facilitate all types of technology development, so as not to prematurely discount any potential option. However, the group also wanted to note that policy and economic issues are paramount to technological considerations, in that they can enable or hinder most potential development options. The group also thought the broader context for wealth creation needed to be considered from several perspectives -- domestic industrial base, export energy, inter-provincial trade, etc.

Key Potential Technologies in 2050

The following map provides an overview of the technologies considered for the various regions of Canada. These include distributed and central generation technologies, as well as various transmission and storage options. Those technologies that are not regionally specific are noted across the top of the map. A detailed listing is provided at the end of this section.

Potential Geographic Nature of Future Electricity Technologies



Summary

The group determined that, in the future, there would be a greater portfolio of electricity system technologies that are diverse and driven by regional differences. There will likely be improvements to the traditional systems and fuels (e.g., cleaner fossil fuel technologies, no-waste nuclear), while also some development of new systems and fuels (e.g., fuel cells with synthetic fuels, SMEs). Overall, the concept of 'waste' from power generation could be eliminated – one person's byproducts are another person's fuel source (e.g., biorefineries).

Future improvements to electricity transmission were thought to be especially important for Canada, because much of the central generation is far from the load. There will likely be improvements in both transmission efficiency and quality (e.g., HVDC, FACTS).

There will also likely be more distributed generation, while still maintaining some central electrical power generation. Distributed sources will be important in both remote rural locations (e.g., run-of-river) and high density urban areas (e.g., district energy systems), with specific applications maximizing local power sources (e.g., wind/wave technologies on the coasts; wind technologies around Gaspe). It was thought that national standards for distributed systems (interconnections) would be important in this future context. Ultimately, power sources could be distributed down to the individual level, with personal power plants and home/car fuel cell mixes that allow for personal power control.

Finally, the future will include overall improved energy management and community planning to conserve and more efficiently use electricity (e.g., automated demand side management, eco-industrial parks).

Potential Future Electricity Sector Technologies – Detailed Listing

National Technologies

Generation

- Photovoltaics (PV) technology breakthrough for multiple energy generation – production of electrical energy directly from the sun's energy and electrolysis of water to provide hydrogen to fuel other power needs (e.g., cars)
- PV paint - new "spray on" technology that is spread over a mesh on buildings to collect the sun's energy - other future material could include paralyne dyes or photosynthetic materials
- New nuclear (mid term option) with short construction, site licensed, better waste breakdown, transmutation enabling technology (e.g., Saskatchewan, 600 MW)
- Sequential bioprocessing – a biorefinery with fully integrated/expansion of biofuels and biofeeds (burn waste for power)
- Personal power plant to power one's home and office needs, with an improved PEM

(proton exchange membrane) Fuel Cell -- this technology would require a convenient and lightweight power source (Hydrogen)

- Nano-technologies – small generation technologies (e.g., nanoturbine), as well as the use of smaller technologies that use less power (e.g., industrial applications); this would require enabling manufacturing technology (i.e., miniaturized computer technology)
- Fuel cell/Gas turbine Hybrid which could produce high efficiency electricity in a distributed manner
- Combined heat and power co-generation, which would be large but localized (i.e., application-specific)
- Non-fossil fuels manufacture/Synthetic Fuels/Biofuels – for fuel cells, urban use, “peaking”
- RAM jet turbines for electricity generation (essentially a combustor outside a big flywheel)
- Thermoelectric – manufacture of electricity from heat

Transmission

- Flexible AC Transmission Systems (FACTS), with increase quality and flow control, as well as up to 50% more transmission; could also involve Gate TurnOff (GTO) technology
- Coast to coast HVDC distribution system, with low loss transmission, increased flexibility, and advanced switching
- Low voltage DC, for long distances using long skinny transmission lines, linked to DC Industrial Parks (that use DC straight from DC transmission, therefore no inverter loss converting to AC)
- Wireless transmission

Storage

- SMEs superconductivity (high density, rapid response energy sinks)
- Improved flywheel

Energy Management

- Community Energy Planning – a myriad of technologies to conserve energy and/or improve efficiency. For example, ceramic heat exchangers, thermoelectric or geothermal heat pumps, Automated Demand Management Technology (which would make being energy efficient effortless and financially attractive e.g., “white meter” automatic load leveling)
- Self sufficient rural homes
- Eco-Industrial Parks/“Plexes”
- Dialing power on demand, like a satellite dish for power

British Columbia Technologies

- Large hydroelectric, particularly on rivers with existing dam structures

- Biomass
- Run-of-river
- Free stream turbine (vertical axis turbine in waterways) – which can operate with low flows but would be most applicable where there was little boat traffic
- Wind/wave ‘osprey’ – a platform that serves as a breakwater, as well as a platform for a wind and air turbine
- Tidal/wave generation, with no fish intake or destruction

Alberta Technologies

- Clean fossil technologies -- combined cycle (gas), coal bed methane, and closed cycle coal
- CO2 pipeline across the province
- Co-firing wood waste and coal¹
- Biofuels (butane) plus biofeed expansion
- Vertical axis wind turbine - localized service for rural populations

Saskatchewan Technologies

- Vertical axis wind turbine - localized service for rural populations
- No waste nuclear

Manitoba Technologies

- Large hydroelectric (largely existing infrastructure)
- Run of river for remote areas
- High voltage transmissions (more or bigger plants further away from site)

Ontario Technologies

- Free stream turbine (vertical axis turbine in waterways) – which can operate with low flows but would be most applicable where there was little boat traffic
- Life extended “new” nuclear¹
- Thermo-electric¹

Quebec Technologies

- Vertical axis wind turbine - localized service for rural populations (Gaspé)
- Free stream turbine (vertical axis turbine in waterways) – which can operate with low flows but would be most applicable where there was little boat traffic

Maritime Technologies

- Co-firing wood waste and coal
- Free stream turbine (vertical axis turbine in waterways) – can operate with low flows but would be most applicable where there was little boat traffic

¹ Added by other workshop participants in the ‘walk-about’

- Wind/wave 'osprey' – a platform that serves as a breakwater, and a platform for a wind and air turbine
- Tidal/wave generation, with no fish intake or destruction

Northern Technologies

- Electricity from remote northern gas
- Canadian Arctic unique technology needs – commercial product opportunities (internationally)¹

Urban Technologies

- District energy systems (centralized heating & cooling) – distributed generation with combined heat and power produced. For example, in high density neighbourhoods each building would have a generator on the roof, and several buildings would be linked for contingencies. The system could include, in the near term, combustion turbine generation (gas), and, over the longer term, fuel cell generation, as well as advanced heat recovery and adsorption chillers.
- Peak shaving technologies – fuel cell car that plugs into the home and provides additional power at peak times (e.g., right after work) and then, at night when the household power needs are low, the house electricity recharges the car. This leads to more efficient centralized system.

Key Obstacles

- Nuclear – waste disposal
- Biomass - transportation
- Hydropower – fish destruction
- Solar – Canada not good for electricity production, rather for fuel savings/efficiency
- PV – niche markets (remote communication systems, high end buildings/office towers) but not major impact

Breakout Group "B"

Technology Step-Out Group

Team Members

Malcolm McDonald, TransAlta Utilities
Marlo Raynolds, Pembina Institute
Duane Pendergast, Atomic Energy of Canada Ltd.
Jim Bowman, Babcock and Wilcox
Blair Seckington, Ontario Hydro
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Joyce Mclean, Toronto Hydro
Lindsey Patrick, ETF, NRCan
Douglas J. Russell, GCSI (facilitator)
Michael Bishop, GCSI (rapporteur)

Challenge

To brainstorm over technologies that could emerge over the long-term to make electricity production, transmission, and distribution within Canada sustainable (reduced greenhouse gas emissions). The emphasis in the technology step-out group was to look at the timing of the commercialization of electricity technologies from the year 2000 to 2050, milestones and barriers in implementation, and the role of centralized and de-centralized technologies.

Expectations of Participants

The comments made by participants about their role in and expectations of the ETF process were centered on three themes:

- **Exchange of Information and Viewpoints**

Participants were interested in integrating viewpoints and contributing to some kind of vision about the future, particularly from a Canadian standpoint. They hoped that this would help them understand possible futures and other people's ideas about the future. It was recognised that an open mind is required and that the subject matter required thinking outside the bounds of CO2 reductions and outside the electricity industry.

- **"Positioning" of Canada and Industry**

Canada will need to focus on its core competencies and any competitive advantages it may have (e.g. natural resources) when addressing the issue of sustainable electricity technologies and systems. This will ensure that Canada stays competitive overall. Seeds will have to be planted in the near-term, though, for appropriate technologies to develop over the 2000-2050 period. Considering that adjustment will be required, a clear signal from Canada would be helpful.

- **Technology and Society**

It was recognised that the workshop break-out group will have to look at possible changes in consumer preferences for electricity, the integration of low and high technology solutions, and the notion of technology availability versus implementation in the Canadian context. Technological solutions for a sustainable electricity sector must also be seen as practical and realistic.

Key Points

The results of the team brainstorming session (see Table) were evaluated by participants and the following key points emerged out of the discussions:

Dominance of Fossil Fuels

- Fossil fuel is expected to remain the dominant fuel type for electricity industry over the 2000-2050 period. However, steps will have to be taken to ensure that it is cleaner and less GHG intensive, eg. through carbon dioxide sequestration. It is recognized that fossil fuel is entering a 'transition' phase, where renewable and other energy fuels increasingly take market share. In order to maximize the benefits of fossil fuel and lever society to a non-fossil fuel future, its full potential energy output must be realized (through energy efficiency efforts such as combined heat and power systems). The energy transition might be seen in the trend towards energy plexes (fossil fuel and renewable/nuclear hybrids), which will begin as decentralized technologies but emerge into centralized ones (at a municipality or city level).
- An *evolutionary pattern* can be seen for technologies. Considering the long life-cycle of technologies, there is no clear break in technology development. The emergence of mixed fuel energy plexes as described above is one example, as part of the trend towards decentralized technologies.
- There will be *increasing diversity* of energy production technologies. Many niche markets will exist for various fossil fuel and renewable energy technologies, depending on location/availability of fuels, and expand through time in the energy 'transition' phase.
- There will be an *enhanced role for renewable energy*. Although it is expected to remain a niche technology until 2030, there may be some large centralized renewable energy systems by 2050. Greater growth will be seen under a 'decentralized' scenario. There is the recognition that storage technologies will play an important role in their development.
- There will be an *integration of centralized and decentralized electricity systems*. In order to ensure the stability of a move towards a decentralized system (or even "mini-grids" and "home energy systems"), a large baseload technology (eg. large hydro, nuclear) or energy plexes will be required and/or viable. The lowering or elimination of

interprovincial barriers in electricity trade may also provide some help, as well as advanced power control systems and transmission technologies.

- *Storage* will be a key enabling technology in the move towards decentralized electricity systems. This may be in the form of large hydropower, hydrogen, or other storage devices (eg. chemical).
- There are possible *Canadian opportunities* in developing future technologies for the electricity industry. Suggestions included: fuel cells and spin-offs; fossil fuel (esp. tar sand) sequestration technologies; CANDUs; end-use conservation technologies; cross-cutting technologies, eg. advanced materials and control systems; biomass utilization technologies; district heating/cooling systems; technologies tailored to winter climates.
- A *research and development thrust* is required for the development of Canadian technologies.

Technology Step-Out Group "Sticky" Board

YEAR	STORAGE	TRANSMISSION	CO ² HANDLING	USE/CONSUMPTION	CROSS-CUTTING
2050+					
2050	hydrogen	wireless power transfer		smart buildings	advanced materials
				individual generating capacity	
2040	super-conducting magnetic energy storage (SMES)	super-conductive transmission- inter-provincial, line loss <4%	hydrogen addition to fossil fuels e.g. tar sands from non-fossil or CO ² -neutral source		
2030	electricity storage box	advanced power systems controls (stability)	fluid-bed re-powering of coal-fired power stations	half reduction in lighting electricity consumption	
			coal-gasification (pressurized fluid bed), combined cycle	half reduction in residential electricity consumption	
2020	regenerative 2-way fuel cells (storage capacity)	flexible AC transmission	cost-effective CO ² extraction technology, geological storage	home energy system	
			coal- CO ² recovery, O ² firing, CO ² conversion	electro-technologies	
2010				full utilization of ground source heat pumps	
	large hydro	advanced flywheels	coal-fired conventional power with CO ² extraction & storage	enhanced oil, gas & tar sand production using CO ² injection	advanced industrial energy efficiency programmes
2000					

Technology Step-Out "Sticky" Board

YEAR	FOSSIL FUELS	RENEWABLE ENERGY	HYDROGEN	NUCLEAR
2050+				
2050	nuclear/tar/hydro gen plex	micro-Sterling engines running on biomass	photovoltaic paint, roads, etc.	nuclear fusion advanced fission
2040	hybrid coal plexes	cogeneration- large/small, using urban planning to accomplish	geothermal tidal/wave power	nuclear waste transmutation
2030	integrated gasification coal fuel cells	combined centralized & distributed systems- district heating, energy complex		hydrogen energy currency
	district heating & cooling	fully-integrated industrial ecology systems (using waste as feedstock to other industries)	community solar projects	hydrogen-fuelled transportation system
2020	large city cogeneration/dis trict heating infrastructure	eco-industrial development	wind farms across country	wind with electrolysis hydrogen storage
			solar- high efficiency storage, low capital costs, low interconnection costs	
2010		industrial fuel cell	economic PV, integrated into buildings and efficient storage	nuclear fission
		fuel cell generation combined cycle plants	renewable solar and wind power	nuclear- extended life, waste management, advanced design, fission development
2000	industrial cogeneration	high efficiency natural gas combined cycle power stations (200- 300MWe)	cost-competitive wind power generation	
		waste-to-energy (sewage/landfill)	lake thermal cooling	
			solar tile buildings integration	

Notes: 1. Stickies were posted to indicate timing of commercialization of technologies

Breakout Group "C"

Enabling Technologies – The "Skywalkers/Vision" Group

Team Members

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Steve Gehl, EPRI
Andrew Stuart, Stuart Energy Systems
Don MacDonald, Alberta Department of Energy
Julian Cage, IREQ
Christine Elwell, Sierra Club of Canada (morning session only)
John Rinella, Ontario Ministry of Energy, Science, and Technology
Carole Champion, ETF
David Reeve, GCSI (facilitator)
Cathy Wilkinson, GCSI (rapporteur)

Challenge

The challenge for the group was to develop *one or more visions* of what the electricity sector could look like in the year 2050, and to identify *key enabling technologies* that could help Canada achieve those visions.

While the group recognized that the purpose of the workshop was to focus on *technologies* (as opposed to policy or regulatory issues), group members identified a number of overarching issues that they felt would significantly influence the structure of the electricity sector in 2050. These included:

- International considerations (i.e. the Canadian industry in the context of North America and the world);
- Issues related to market pull or market directions ("uptake is everything"); and
- The status of the Kyoto commitment (i.e. will Canada and the world ratify the Protocol? Will developing countries take on commitments?)

Scenarios

While keeping in mind the factors identified above, the group developed two visions or scenarios for the electricity sector in the year 2050. **Scenario 1** represented the sector if Kyoto-like carbon constraints were imposed in Canada. The group felt that this scenario would require *incremental* technology development and commercialization. **Scenario 2** envisaged severe carbon constraints in 2050, which, in the group's view, would require a *paradigm shift* with respect to the technologies employed within the electricity sector.

In both scenarios, group members felt that the electricity sector is likely to be part of an *increasingly integrated* energy system by the year 2050. *Diversity* of electricity sources, with an increased focus on *distributed* power, was seen to be an important characteristic of the future system. The group also indicated that a greater portion of market share within the sector would be captured by non-carbon electricity services, with the power grid emerging as a key mechanism for transmitting non-fossil energy. *Enhanced network flexibility* was envisaged through *increased storage capacity*, which will be particularly important for intermittent renewables. The development of new materials as seen as key, with properties amenable to, for example, the construction of high temperature turbines and advanced storage devices. It was agreed that *quality of product* and issues related to *network protection* are likely to be key issues in 2050.

Key Potential Technologies in 2050

Based on the scenarios outlined above, the group then identified a series of technologies that they felt could be part of the electricity sector in 2050. However, group members emphasized that specific technologies should be subject to cost/benefit analysis prior to being established as priorities for either the private sector or the federal government.

Significantly, most of the technologies identified by the group applied to both scenarios. In other words, the same technologies that were identified in the Kyoto-based scenario were also likely to be employed in a more carbon constrained future. The difference between these two scenarios likely relates primarily to the *rapidity* of change within the sector, or the *degree of uptake* of various technologies.

Technologies identified for both scenarios were then categorized according to whether or not they related primarily to generation, storage, transmission, or utilization. Examples of *generation* technologies identified included zero carbon emission plants, sequestration technologies, and low cost biomass gasification. The *storage* category included superconductivity coils, CAES, and flywheels. Advanced wireless and microwave technologies were considered key to the *transmission* of electricity in 2050. After some debate, the group also addressed *utilization* technologies, highlighting in particular those associated with the concept of an 'electrified city'. A full list of technologies identified by the group is found at the end of this section.

It was also noted that some technologies (such as superconductivity) represent *whole systems*, as they apply to all aspects of the electricity sector (including generation, transmission, etc). The time and will required to overhaul complete systems to accommodate such technologies was identified as a significant barrier to their further development and commercialization.

Key Enabling Technologies

The group spent the remainder of their time identifying the key *enabling technologies* which would be necessary to ensure the development of those technologies seen to be critical components of the electricity system in the year 2050.

As in the previous exercise, technologies were categorized according to whether or not they apply primarily to the generation, storage, transmission, or utilization of electricity. Key enabling technologies for electricity *generation* included nanotechnologies (or localized small devices); high efficiency wide spectrum photovoltaics (for solar technologies), and high efficiency design for high temperature fission. With respect to electricity *storage*, lower cost availability of materials, and developing advanced manufacturing technologies (e.g. hydrogen) were identified as potential needs. Issues related to storage were seen by some group members to require particular attention, given the likely future structure of the sector.

Network design flexibility of superconductors, such as 4 quadrant SMES, was identified as a priority in the area of electricity transmission, in addition to demonstrations of space-based wireless and/or microwave technology. Utilization technologies, particularly related to the 'electrified city', included computerized controls and the integration of computers, communications systems, and electricity.

A complete list of enabling technologies identified in this exercise is appended (see Annex B).

Additional Issues

A number of additional issues were identified by group members in the course of the break-out discussion. Key among these was the issue for how to plan and deal with the inevitable *uncertainties* associated with the development of new technologies. In addition, group members emphasized the importance of examining *life-cycle emissions* with respect to particular technologies, as well as the need to *properly design and resource research and development programs*.

Electricity Sector Technologies in the Year 2050

Generation

- Zero carbon emission plants/very high efficiency gas turbines
- All sources, fully integrated
- Sequestration
- On-site generation without grid connection
- Extremely distributed generation
- Integrated electricity/methane/hydrogen infrastructure
- Low cost biomass gasification

Storage

- Pumped hydro
- Reservoirs
- H2/Batteries/CAES/Flywheels/superconductivity coils
- Network flexibility (power quality/network protection)

- DC technologies, e.g. inverters

Transmission

- Advanced – wireless/microwave/space/superconductivity
- Non-peak electricity to markets via hydrogen

Utilization

- Improved – greater penetration of non-carbon electricity sources
- Electrified city – greater electrification

Enabling Technologies

Generation

- high efficiency gas turbines
- capture technologies
- integration of solid oxide fuel cell into closed system
- sequestration
- integration of power from different fuels
- high efficiency wide spectrum photovoltaics (solar technologies)
- high efficiency design – high temperature fission
- more integrated fuel cycles (fission)
- optimization of reservoirs using renewables (particularly wind)
- nanotechnologies (localized small devices)
- how to get useful energy services to people in a sustainable fashion

Storage

- lower cost availability of materials
- overcoming exotic resource limitations (e.g. gallium)
- advanced manufacturing technologies (hydrogen)
- more efficient pumps (CAES)
- materials
 - high temperature superconductivity
 - high current capacity in magnetic fields
- high pressure tank embrittlement (hydrogen materials)
- nanotubes (storage systems) – hydrogen
- lightweight systems of storing e.g. hydrogen transport

Transmission

- superconductivity
- network design flexibility of superconductors
 - 4 quadrant SMES

- transformers
- current limiters
- high powered cables (increased current, decreased voltage)
- micron thick coated conductors with high current carrying capacity with good capacity in magnetic fields operating in liquid nitrogen
- power electronics, FACTs (flexible AC transmission systems)
- long distance power wheels to take advantage of low cost resources (eg flared gas from Northern slope)
- demonstrations of wireless/microwave technology (space-based)
 - need to evaluate effect of microwaves on animals/people
- rectantennae design
- space based fabrication/construction
- super-strong space tether
- deep heat from core of earth (hole)
- sub-nano control of power electrons (including messenger electrons as well as labourer electrons in the power/signal stream)

Utilization

- computerized control
- integration of computer/communications/electricity
- command/control/intelligence/communications integration

¹ added by other workshop participants in the 'walk-about'.

ANNEX 1

Workshop Participants

ANNEX 2

Overview Of The Energy Technology Futures Project

ANNEX 3

EPRI Electricity Technology Roadmap by Steve Gehl

ANNEX 4

Emerging Trends in Electric Power Generation by Mark Tinkler, **Ontario Hydro Technologies**

ANNEX 5

Oak Ridge National Laboratory CO₂ Reduction Technologies

ANNEX 6

Green Energy Coalition Fact Sheet, Sierra Club of Canada

ANNEX 7

Round Table Future Scan,
Electricity Technologies in the Year 2050